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FAT CONTENT OF AMERICAN KESTRELS (*FALCO SPARVERIUS*)
AND SHARP-SHINNED HAWKS (*ACCIPITER STRIATUS*)
ESTIMATED BY TOTAL BODY ELECTRICAL CONDUCTIVITY

by

Shari M. Harden

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Biology

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Shari M. Harden

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ABSTRACT

Fat Content of American Kestrels (*Falco sparverius*) and Sharp-
Shinned Hawks (*Accipiter striatus*) Estimated by Total Body
Electrical Conductivity

by

Shari M. Harden, Master of Science

Utah State University, 1993

Major Professor: Dr. James A. Gessaman
Department: Biology

Total body electrical conductivity (TOBEC) is a noninvasive method for the estimation of lean mass in live subjects. Lipid content can be calculated from the body mass measured and the lean mass estimated from TOBEC. I used live American Kestrels (*Falco sparverius*) to study the accuracy of this method. TOBEC measurements were compared to actual body content determined by Soxhlet fat extraction using petroleum ether as the solvent. TOBEC estimated 73.7% of the variation in lean mass in a sample of 21 kestrels. The use of restraining devices (Vetrap and cardboard

cylinders) altered the TOBEC measurement but only by an average of 1.92% and 0.83%, respectively. TOBEC estimated 83.8% of the variation in lean mass for 21 kestrel carcasses warmed to 39.8°C. No significant difference was found between the slope or elevation of the calibration lines developed using live or dead kestrels. A significant difference was found between measurements taken at two different positions. Body temperature altered the TOBEC measurements by an average of 1.54% (SE = 0.55) for each 1°C change over a temperature range of 7.0°C (37.3-44.4). The calibration line developed for kestrels was used to estimate lean mass and compute fat mass of migrating kestrels, Sharp-shinned Hawks (*Accipiter striatus*) and Merlins (*Falco columbarius*). The average percent fat mass of kestrels trapped during migration at Cape May, New Jersey, was 6.01% (SE = 1.92, n = 12) for males and 8.51% (SE = 2.00, n = 13) for females. The difference in lean mass between male and female, and between early, mid-season, and late migrating Sharp-shinned Hawks differed significantly during migration. The fat mass of Sharp-shinned Hawks averaged 5.55% (SE = 0.94, n = 53) for males and 10.92% (SE = 0.80, n = 87) for

females. Male Merlins had an average fat mass of 18.05% (SE = 3.35, n = 7) and females averaged 14.19% (SE = 3.15, n = 8).

(50 pages)

INTRODUCTION

Fat is the principal form for the storage of energy in many animals, including birds. Fat contains more than twice as much energy as carbohydrate, making it the preferred mode of energy storage, especially in birds that require fuel for the migratory flight without expending excess energy to keep the fuel aloft (Schmidt-Nielsen 1990). Since a small change in fat content can cause significant changes in the energy content of the total body (Gessaman 1987), researchers measure fat content as an indicator of overall health.

In the past, measurement of body fat in birds required sacrificing experimental animals. Sacrificing experimental animals would be detrimental for studies that involved endangered species, for tracking individuals through developmental stages, for studying birds during migration or under various environmental conditions. The Soxhlet lipid extraction method provides a direct measure of fat, but requires sacrifice of the experimental animals. Dobush et al. (1985) studied fat extraction methods using petroleum ether, diethyl ether, and chloroform-methanol as

solvents. Results of their study suggest that petroleum ether extracts less nonlipid material than chloroform-methanol. The time required for extraction of lipids was much shorter for petroleum ether, 6 hours, than for chloroform-methanol, 48 hours.

In an attempt to avoid sacrificing animals, researchers have tried to develop alternative methods of determining fat content. The accuracy of one mildly invasive method (tritium dilution) and four noninvasive methods--fat scoring, infrared interactance, cyclopropane, and total body electrical conductivity (TOBEC)--have been evaluated in recent years.

Tritiated water has been used to determine the fat content in passerine birds (Gauthier and Thomas 1990). The tritiated water method estimates fat content indirectly by measuring the water content depending upon the principle that stored fat does not contain water; therefore, as the fat content increases, the percent body water decreases. Gauthier and Thomas (1990) concluded that the tritiated water method was unreliable in the measurement of fat content in individual birds, with errors ranging from 25 to 150%.

Fat scoring has been used as a nondestructive method to quantify the amount of fat on a bird (Moore and Kerlinger 1987; Blem and Shelor 1986; Rogers 1987). With this method, observers examine certain points on the body (usually in the furcular and abdominal regions) and designate a numerical value to represent the amount of visible fat. Unfortunately, this method is subject to variation between and within examiners (Krementz and Pendleton 1990). In the study by Krementz and Pendleton (1990), fat scores explained less than 50% of the variation in total body fat.

The cyclopropane method, a noninvasive method that has been validated for mammals and turtles, estimates body fat with errors of only 1-6% (Henen 1991). Since cyclopropane gas is more soluble in lipids than in nonlipids, the amount of gas absorbed by an animal will be proportional to the animal's lipid content. Although the cyclopropane method is a fairly accurate, direct measure of lipid content, this process requires many measurements and an extended equilibration time of 1.5-3 hours (Henen 1991).

Infrared interactance (IRI) is another noninvasive method that uses low-energy electromagnetic radiation to estimate body

composition. With the IRI method, measurements are taken at various positions on the surface of the skin. In the study by Roby (1991) the subscapular, pectoralis, and subfemoral locations were measured. Roby (1991) used both the near-infrared interactance (IRI) and total body electrical conductivity (TOBEC) to determine fat content of the same Northern Bobwhites (*Colinus virginianus*). The IRI method explained only 17.5% and 10.0% of the variation in percentage of body lipid measured at two sites on the body (subscapular and pectoralis).

Measurement of the TOBEC to estimate lean mass is a noninvasive procedure that uses a 10-megahertz oscillating magnetic field and determines the nature of the conductive material within the EM-SCAN chamber by detecting changes in the impedance of the radiating coils (Anonymous 1990). Fat-free mass contains more sodium and potassium than fat, a difference that will alter conduction of electromagnetic resonance through the body. The TOBEC device estimates the lean mass which, when subtracted from the total mass, equals the fat content of the animal. Several factors have been shown to affect the TOBEC

measurement on an animal: position of the animal's body in the measurement chamber, body temperature of the animal, dehydration, and the presence of identification bands on the animal (Walsberg 1988; Scott et al. 1991).

Due to the nature of the magnetic field, the position of the subject in the chamber must be standardized for all measurements. The electromagnetic field intensity peaks 15.24 cm from the distal end of the chamber and runs most effectively for a length of approximately 10.16 cm (Anonymous 1990). The portion of the animal positioned within this area of the chamber will determine the measure of fat-free mass. The SA-2 model (EM-SCAN) operates in either of two separate modes. The fixed mode takes one measurement in approximately one second, and each animal must be positioned in the same place for good results. The peak mode, which takes measurements continuously as the animal is slowly inserted into the chamber, requires an immobile subject and approximately 10 seconds for each reading. For field use, the fixed mode is more practical because the peak mode requires the use of anesthesia to sedate the animals.

A body temperature variation of 4°C may cause a 5% error in the estimate of lean body mass from TOBEC, although this error should not be present when observing homeotherms that are not under thermal stress and that have minimal activity (Walsberg 1988). Castro et al. (1990) and Roby (1991) reported that the TOBEC method may be used on birds banded with USFWS aluminum bands without significantly altering the measurements. In contrast, Scott et al. (1991) found that a band increased the TOBEC index 13%, 40%, and 45%, respectively, on dunlin (*Calidris alpina*), redshank (*Tringa totanus*), and turnstone (*Arenaria interpres*). The band size for both the turnstone and redshank was significantly larger than for the dunlin and the bands were believed to be of a different metal alloy. Calibration of this instrument is necessary for use with each species that differs significantly in body size, as well as with live and dead animals of the same species that differ in body temperature (Castro et al. 1990). The TOBEC method has been used in studies of birds (Castro et al. 1990; Walsberg 1988; Roby 1991; Morton et al. 1991), humans (Van Loan et al. 1987; Van Loan and Koehler 1990; Presta et al. 1983), and other

mammals (Keim et al. 1988).

A fast, noninvasive method would be useful for field studies and would enable researchers to take multiple measurements on individual birds or groups of birds. Measurements of fat content are needed to determine the energetic costs associated with breeding, molt, and migration. Field measurements of fat content in raptors are important to indicate the overall health of the birds. A low fat content may indicate poor health due to disease or a decrease in available food. The health of raptors is often used as an indicator of pollutants in the environment. Predatory bird populations are at greater risk to the toxic side effects of pollutants, due to the accumulation of toxins in the food chain. In the case of many pesticides, the prey species may be relatively insensitive to the toxic effects, but in the raptors that consume them the pollutants may reach levels that will cause mortality or decreased reproductive success (Newton and Haas 1984). To date, very little research has been published on fat content in raptors using any method of fat measurement. Geller and Temple (1983) studied subcutaneous fat deposits in migratory juvenile Red-tailed

Hawks (*Buteo jamaicensis*) using a form of fat scoring; the fat on each bird was ranked on a scale of 1-6. Gessaman (1979) used the Soxhlet extraction method to measure fat content in American Kestrels (*Falco sparverius*), finding in September female kestrels had 7.0% body fat and males had 5.3%, while in July both males and females had 3-4% body fat. The fluctuation of body weight of European Kestrels (*Falco tinnunculus*) over time was studied by Village (1990). The differences in weight variations between the sexes were attributed to the different roles of males and females during courtship and breeding. The changes in body weight were expected to represent changes in fat reserves, but no measurement of fat was obtained. Clark (1985) used a visual fat index to record the subcutaneous fat of migrant Merlins (*Falco columbarius*) captured at Cape May Point, New Jersey, during fall migration of 1978 and 1979. A trace or more of fat was found on 232 of 279 Merlins. Weight was not significantly correlated with fat deposition.

In this study, the EM-SCAN instrument was calibrated for the American Kestrel and was used to estimate the body fat of

Kestrels, Merlins, and Sharp-shinned Hawks (*Accipiter striatus*) captured at Cape May, New Jersey, during fall migration 1991. Sharp-shinned Hawks and Merlins were included in this study due to their similarity in size to kestrels. The migrating raptors were studied to determine whether fat content varies between males and females and between early and late migrants. The effect of restraining devices, body temperature, and position of the bird in the measurement chamber were also studied.

METHODS

I measured the total body electrical conductivity (TOBEC) of kestrels with an SA-2 model instrument made by EM-SCAN that was interfaced with a Zenith 286 Supersport personal computer. Three animal carrier trays of different thickness were supplied with the device, and a scribe mark was etched into each tray to mark the point of peak electromagnetic intensity with the end of the tray positioned against the distal wall of the measurement chamber. The smallest tray was used for this study, and the restrained birds, laying on their backs, were placed head first into the chamber with the top of their heads 7.5 cm from the distal end. Unlike the previous model (SA-1), the SA-2 took a reference reading of the empty chamber prior to each animal measurement.

Lean mass of 25 kestrels (12 male and 13 female), obtained from Patuxent Wildlife Research Center in Laurel, Maryland, was estimated with the EM-SCAN instrument and measured by Soxhlet fat extraction. A series of three live TOBEC measurements was obtained on each kestrel just prior to sacrificing with CO₂; then the birds were placed in plastic bags, immediately frozen, and

shipped to Utah State University for fat extraction. The mean live TOBEC measurements were compared to the actual fat and lean mass by regression analysis.

Restraining devices were used to minimize movement of the birds during the TOBEC measurements. At Patuxent, Vetrap bandaging tape (3M Inc.) was used to restrain the birds. The measurement of the Vetrap placed in the chamber without a bird was measured, and this measurement was subtracted from the TOBEC number obtained with each bird. The Vetrap was wrapped around each bird with wings held close to the body, and the same piece of Vetrap was used for the study comparing the TOBEC measurements on the Patuxent birds before and after they were sacrificed. At Cape May, cardboard cylinders were used to restrain the birds. As with the Vetrap, measurements of the empty cylinder were subtracted from measurements with the bird inside the cylinder. To determine whether use of restraining devices would alter the TOBEC values, measurements taken with Vetrap wrapped around the carcasses were compared to the measurements without Vetrap, and measurements with and without a cardboard

cylinder were also compared using a paired t-test. The use of bands was also studied by using two kestrels thawed to approximately 40°C. Four sets of three measurements were taken on each bird with a USFWS aluminum band and without a band and compared with a paired t-test.

Variation in TOBEC measurements with body temperature was studied using 13 birds after they were sacrificed. These birds were thawed with a hot water bath and heating pad, and measurements were taken at body temperatures between 37.3 and 44.4°C. The TOBEC measurements obtained were compared to the lean mass determined by Soxhlet fat extraction.

All of the birds from Patuxent were thawed at U.S.U. and warmed to 39.5-40.1°C in plastic bags immersed in a hot water bath. The TOBEC was then remeasured for each bird to compare values measured at Patuxent on live birds and at U.S.U. on dead birds. The carcasses were also measured three times at two different horizontal positions within the EM-SCAN chamber, approximately 7.5 and 8.5 cm from the distal end of the chamber, to determine if horizontal placement would significantly alter the

accuracy of predicting lean mass from the TOBEC value.

Before fat extraction, the birds were weighed with an electronic balance and feathers removed. The skull and body cavity were cut open to facilitate drying in a freeze-drier. The carcasses remained in the freeze-drier until weight reached a steady state at approximately 5 days and were then weighed to determine dry body mass. The carcasses were finely cut with scissors, placed into filter paper thimbles, and inserted into Soxhlet units. Petroleum ether, heated to 50-70°C, was used as the solvent to remove lipids without extracting nonlipids (Dobush et al. 1985). After distillation for 20-26 hours, the thimbles were placed in a drying oven at 50°C for 24 hours (until the weight reached a steady state), allowed to cool for 10 minutes, and weighed to determine dry, lean mass. The fat mass was obtained by subtracting the dry lean mass from the dry body mass. The lean body mass was then determined by subtracting the fat mass from the total body mass.

At Cape May, New Jersey, the TOBEC of 25 American Kestrels, 14 Merlins, and 140 Sharp-shinned Hawks, captured during

migration, were measured with the EM-SCAN instrument between 26 September and 25 November 1991. The birds were trapped using mist nets and bowtraps. Each bird was banded, weighed, and measured with the EM-SCAN three times usually within 20 minutes of trapping. The length and width of the subalar fat deposit under the left wing was also measured with a clear plastic ruler before the bird was released.

RESULTS

The 21 kestrels used in the calibration of the EM-SCAN instrument weighed between 85.6 and 114.8 g, and their body fat ranged from 0.8 to 4.9 g. The change in the TOBEC value with lean body mass estimated by TOBEC is best described by the equation

$$T_L = 3.552LM - 229.554 \quad (1)$$

$$(r^2 = 0.737; P = 0.0001; SE = 12.83)$$

where T_L is the TOBEC value determined by the EM-SCAN device, and LM is the lean mass determined by the Soxhlet fat extraction method. The lean mass of live kestrels at position 1 (top of head 7.5 cm from distal end of chamber), restrained with Vetrap, can be determined using the following equation:

$$LM = (T_L + 229.554)/3.552 \quad (2)$$

By using this equation, the predicted lean mass for the 21 kestrels differs by an average of -0.01% (SE = 0.77) from the observed lean mass and the calculated fat mass differs by an average of -13.40% (SE = 37.29) from the actual fat mass (Table 1).

The lean mass derived from Equation 2, using the TOBEC

TABLE 1. Actual and predicted values of lean mass and fat mass and the percent difference between the actual and predicted values.

Kestrel	Actual values ¹			Predicted values		Percent difference	
	Body mass Mb	Lean mass MI	Fat mass Mf	Lean mass ² Mlp	Fat mass ³ Mfp	MI-Mlp/MI x100	Mf-Mfp/Mf x100
1	100.1	99.1	1.0	96.24	3.9	2.88	-290.00
2	85.6	84.8	0.8	87.43	-1.8	-3.10	325.00
3	94.6	93.2	1.4	92.40	2.2	0.86	-57.00
4	97.6	96.5	1.1	95.88	1.7	0.64	-54.54
5	91.9	89.7	2.2	90.81	1.1	-1.24	50.00
6	98.9	98.0	0.9	95.31	3.6	2.74	-300.00
7	101.9	98.8	3.1	103.94	-2.0	-5.20	164.52
8	104.0	101.2	2.8	104.60	-0.6	-3.36	121.43
9	96.3	94.9	1.4	94.00	2.3	0.95	-64.28
10	106.4	103.9	2.5	110.61	-4.2	-6.46	268.00
11	94.1	91.8	2.3	86.87	7.2	5.37	-213.04
12	102.8	100.5	2.3	94.00	8.8	6.47	-282.61
13	104.5	100.7	3.8	104.70	-0.2	-3.97	105.26
14	101.1	98.1	3.0	102.44	-1.3	-4.42	143.33
15	94.6	91.7	2.9	92.12	2.5	-0.46	13.79
16	114.8	110.6	4.2	110.14	4.7	0.42	-11.90
17	109.1	106.0	3.1	105.92	3.2	0.07	-3.22
18	109.1	104.2	4.9	102.63	6.5	1.51	-32.65
19	99.7	97.9	1.8	97.56	2.1	0.35	-16.67
20	105.6	101.7	3.9	95.80	9.8	5.80	-151.28
21	102.4	100.1	2.3	100.19	2.2	-0.09	4.35
mean =	100.72	98.26	2.46			-0.01	-13.40
SE =	1.45	1.28	0.25			0.75	37.29

¹ All mass values in grams.

² Calculated with Eq. 2.

³ Calculated: predicted fat mass = actual body mass - predicted lean mass.

measurements taken with Vetrap, was compared to the lean mass derived from the TOBEC measurements taken without Vetrap using a paired t-test. Although the t-test demonstrated a significant difference ($p = 0.0001$, $t = 7.384$, $df = 20$), the difference in calculated lean mass computed from Equation 2 for carcasses wrapped in Vetrap averaged only 1.92% ($SE = 0.32$) greater than for carcasses measured without Vetrap. A significant difference was found at the 95% confidence level, $p = 0.0224$ ($t = 2.619$, $df = 12$), between the lean mass calculated from TOBEC values measured with and without a cardboard cylinder, but the difference in the calculated lean mass using a cylinder was only 0.83% ($SE = 0.32$) less than the lean mass calculated from TOBEC values measured without a cylinder. No significant difference was found between TOBEC measurements taken with a band and those taken without a band, $p = 0.54$ ($t = -0.637$, $df = 7$).

For 13 dead kestrels, multiple TOBEC measurements were taken at various temperatures over a range of 7.0°C (37.3-44.4°C), after which Equation 2 was used to calculate the lean mass for each TOBEC measurement. The average difference in

TOBEC values was 1.54% (SE = 0.55), resulting in an average difference in calculated lean mass of 0.70 g (SE = 0.25) for each 1°C change. An equation to adjust for variation in temperature was not developed due to the variation among individual birds (Figs. 4-16 in Appendix).

Measurements of the carcasses when warmed to 39.8°C were compared to the actual lean mass with simple linear regression analysis, and Equation 3 was obtained:

$$LM = (T_L + 185.817)/3.180 \quad (3)$$

$$(r^2 = 0.838, SE = 8.458, P = 0.0001)$$

The slope and elevation of Equation 3 were compared to the slope and elevation of Equation 2 (Figure 1) in accordance with the methods described in Zar (1984). No significant difference was found at the 95% confidence level (df = 38), in the slope ($t = 1.36$), or in elevation ($t = 1.37$).

A paired t -test was performed to analyze the lean mass calculated from TOBEC values measured at position 1 and position 2 using equation 2; a significant difference was found, $p = 0.0001$ ($t = 8.792$, $df = 20$). The lean mass calculated at position 2

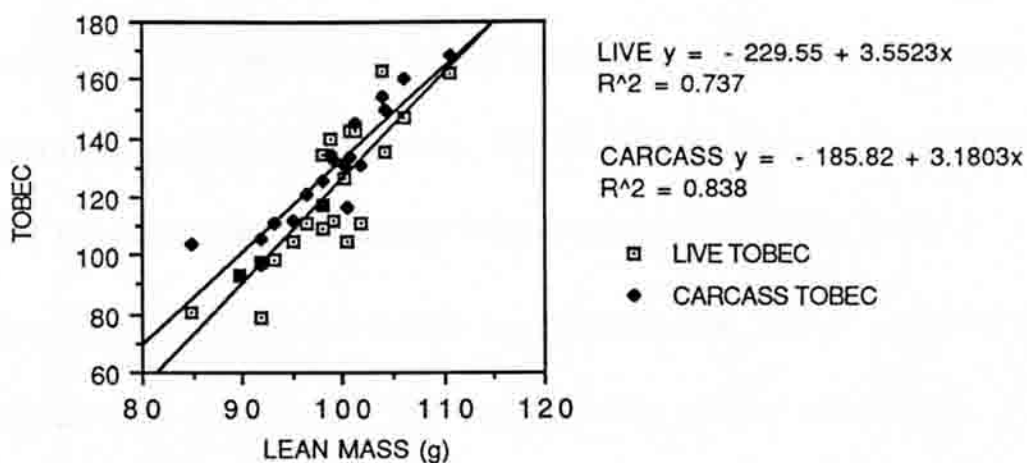


FIGURE 1. Calibration curves for live kestrels and carcasses.

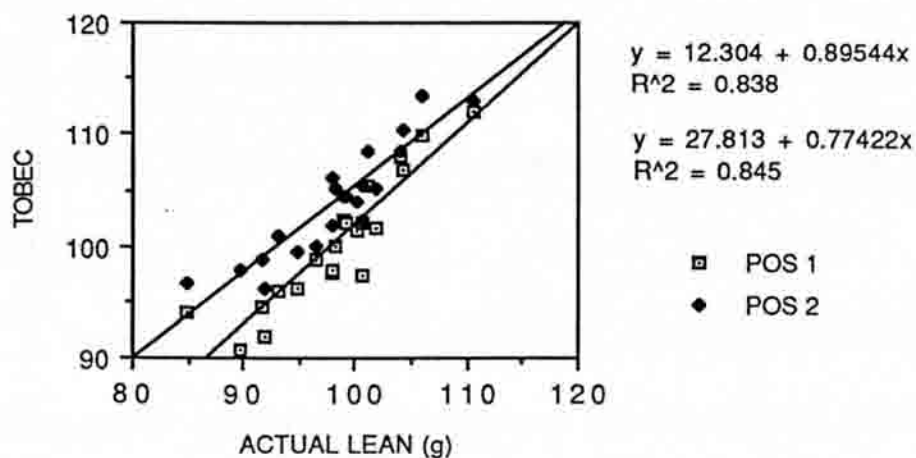


FIGURE 2. Calibration curves for position 1 and position 2.

averaged 3.65% (SE = 0.44) greater than the mass calculated at position 1. To determine which horizontal position would more accurately estimate lean mass, TOBEC values from each position were compared to the actual lean mass using simple linear regression, yielding $r^2 = 0.838$ for position one, and $r^2 = 0.845$ for position two (Figure 2). The homogeneity of the correlation coefficients was compared using the method described in Steel and Torrie (1960), and no significant difference between positions was found, $X^2 = 0.000056$.

No correlation could be determined between the length and width of the visible fat deposits when compared to the lean or fat mass. The best results were obtained from comparing the length of the visible fat to the actual lean mass, $r^2 = 0.114$ ($p = 0.18$, $df = 16$).

Two-sample t-tests were used to compare the mean percentage of lean mass of male and female kestrels (from Patuxent and Cape May), and Sharp-shinned Hawks (from Cape May). A two-way ANOVA was not performed due to the small sample sizes (Table 2). Male and female kestrels from Patuxent and from

TABLE 2. Average percent lean mass of male and female kestrels and Sharp-shinned Hawks and early, mid-season, and late migrators.

Species	Mean estimated Percent lean mass ⁴		Mean calculated Percent fat mass ⁵	
	Males	Females	Males	Females
Kestrels				
From Patuxent	97.40(12)	97.83(9)	2.60	2.17
From Cape May				
Early ¹	96.88(6)	90.12(8)	3.12	9.88
Mid-season ²	89.72(4)	97.78(2)	10.28	2.22
Late ³	93.84(2)	90.92(3)	6.16	9.08
All migrants	93.99(12)	91.49(13)	6.01	8.51
Sharp-shinned Hawks				
Early ¹	95.17(45)	90.26(63)	4.83	9.74
Mid-season ²	91.73(7)	86.01(14)	8.27	13.99
Late ³	80.92(1)	85.87(10)	19.08	14.13
All migrants	94.45(53)	89.08(87)	5.55	10.92
Merlins	81.95(7)	85.81(8)	18.05	14.19

1 Trapped between 26 September-15 October.

2 Trapped between 16 October-4 November.

3 Trapped between 5 November-25 November.

4 Actual percent lean mass for kestrels from Patuxent; calculated for kestrels, Sharp-shinned Hawks, and Merlins from Cape May with Eq. 2.

5 Actual percent fat mass for kestrels from Patuxent; calculated for kestrels, Sharp-shinned Hawks, and Merlins from Cape May using body mass minus lean mass computed with Eq. 2.

Numbers in parentheses indicate number of birds studied.

Cape May did not differ significantly; however, in Sharp-shinned Hawks, the estimated percentage of lean mass was significantly higher, $t_{52} = 4.348$, in males (mean = 94.45%) than the percentage of lean mass in females (mean = 89.08%, Table 2). To determine whether percent of lean mass differs between early and late migrants, the birds were placed into one of three groups depending on the day of capture: 1 - 20 days (26 September - 15 October), 21 - 40 days (16 October - 4 November), and 41 - 60 days (5 November - 25 November). For kestrels, no significant difference was found between early and late migrants, but a significant decline in lean mass over time was found for the Sharp-shinned Hawks ($F_{0.05} = 6.61$, df 2,137). Sharp-shinned Hawks captured between days 1 - 20 averaged 93.06% ($n = 108$) lean mass. Those captured between days 21 - 40 averaged 87.92% ($n = 21$), and between days 41 - 60 averaged 85.42% ($n = 11$). The average percentage of lean mass for the kestrels and Sharp-shinned Hawks at Cape May was 92.74% and 91.76%, respectively. The calculated average fat mass for Sharp-shinned Hawks was 5.55% for males (average body mass, 103.2 g) and 10.92% for

females (average body mass, 174.7 g). The average fat mass of kestrels was 6.01% for males (average body mass, 106.1 g) and 8.51% for females (average body mass, 119.1 g). The average percentage of lean mass estimated for 14 Merlins was 90.01%, 9.99% body fat (Table 2, average body mass for males, 165.0 g, for females, 212.0 g).

DISCUSSION

My study supports findings of Walsberg (1988) and Scott et al. (1991) who reported that TOBEC measurements are a good predictor of lean mass of live animals but not of fat mass (Fig. 3, in Appendix). Since lipid mass always represents a smaller proportion of avian body mass than lean mass, the proportional error will be correspondingly larger for estimates of lipid fraction than the lean fraction. Due to the variation between the predicted and the actual values, I suggest pooled data from a group of birds be used to obtain better results. The average amount of fat mass could be used to compare groups of birds before and after migration, during breeding and molt, or for comparing sex and age classes.

In previous studies, the EM-SCAN instrument has provided good estimates of the lean mass of birds over a wide range of weights. Walsberg (1988) found that TOBEC values accounted for 98.8% of the variance in measured lean mass using 25 birds of fifteen species that ranged in weight from 14.6 to 170.0 g. Roby

(1991) reported that TOBEC values accounted for 92% of the variance in measured lean mass using 62 Northern Bobwhites (*Colinus virginianus*) with weights of 172-278 g. Moreover, Castro et al. (1990) reported that TOBEC values accounted for 95% of the variance in lean mass for 38 birds of five species with weights ranging between 18-90 g. In this study, the r^2 value was much lower, 0.737, for 21 birds of one species with a more narrow weight range from 85.6-114.8 g. Scott et al. (1991) demonstrated that pooling data from different species can improve the r^2 and p values, but the interspecific calibration curve will not be as accurate as calibration lines developed for each species separately. They reported r^2 values of 0.71, 0.67, 0.93, and 0.90 for calibration equations for each of four species, but a r^2 value of 0.95 was obtained when all four species were combined.

The use of Vetrap and cardboard cylinders influenced the TOBEC measurement, but the average percentage of difference in calculated lean mass caused by this influence was minor, 1.92% for Vetrap and 0.83% for the cylinder. The cardboard cylinder caused less variation in the TOBEC measurements, possibly because it

covered the bird's head entirely and allowed less movement. The use of bands did not significantly alter the TOBEC measurements, supporting earlier work by Castro et al. (1990) and Roby (1991).

Variation in temperature also alters the TOBEC values; I found a variation of 1.54% in the TOBEC measurement for each 1°C change. Scott et al. (1991) also found a change in the TOBEC index of 1.53% for dunlin and 1.44% for knot for each 1°C change. An equation to correct for changes in body temperature was not developed due to the variation in the relationship between temperature and TOBEC measurement among individual birds. In future studies, the temperature should be monitored to restrict the amount of error associated with variation in temperature.

Calibration curves developed from TOBEC values measured on a live bird and on that same bird several days after being euthanized and reheated to normal body temperature were not significantly different. Castro et al. (1990) found that TOBEC measurements on carcasses equilibrated to room temperature cannot be used to generate calibration equations for live birds. If carcasses are used to develop calibration curves, they should

be warmed to body temperature.

In this study, using either of two horizontal positions approximately one centimeter apart would not significantly alter the accuracy of the calibration equation produced; however, the horizontal movement of a subject will produce a significant difference in the lean mass derived from an equation established at one position. I found an average increase of 3.65% in calculated lean mass when the bird was placed approximately one centimeter deeper into the chamber. Roby (1991) reported that the coefficient of variation in EM-SCAN number associated with variation in position of the subject in the chamber averaged 1.24%. Each subject should be positioned in the chamber in the same place for each measurement.

In this study it was found that visible fat is not a good indicator of fat content; there was no correlation between length, width, or length x width x π and the actual amount of fat. Although the measurement of the subalar fat was not correlated to fat content, the use of other fat scoring methods may yield better results. Krementz and Pendleton (1990) looked at visible

fat in the furcular and abdominal regions, and obtained better results with fat scores accounting for 50% of the variation in total body fat.

Female Sharp-shinned Hawks, captured during migration, have a significantly lower percentage of lean mass compared to males. This variation between males and females may be attributed to the larger mass of the females. With an increase in weight, the power needed to fly also increases and larger fat reserves will be necessary (Blem 1980). The Sharp-shinned Hawks migrating later in the fall also show a significantly lower lean mass compared to early migrants. These late migrants may have just begun their migratory flight or were fledged from an area farther north with a more ample food supply. Either possibility could increase the fat content measured at Cape May. The female kestrels also displayed a lower lean mass than the males, but this difference was not significant. The lack of a significant difference in lean mass among kestrels may have been caused by the much smaller sample size, $n = 25$ kestrels, as compared to $n = 140$ Sharp-shinned Hawks.

If the kestrel sample size had been larger, a significant

difference may have been found. I would suggest using a larger sample size than 25, preferably as large as the sample size of the Sharp-shinned Hawks. In future studies, measurements of birds at different points along the migration route may yield more information about the amount of fat used during migration, and the energetic costs of migration.

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APPENDIX

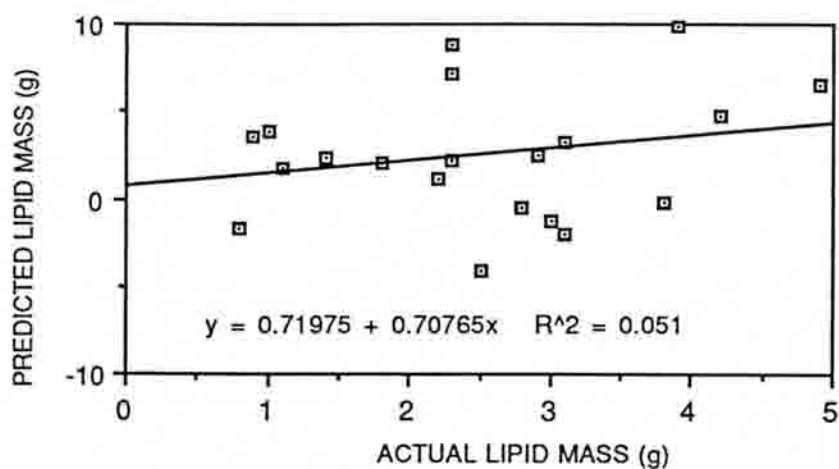


FIGURE 3. Estimates of lipid mass calculated from equation 2 compared to the actual lipid mass determined by soxhlet extraction.

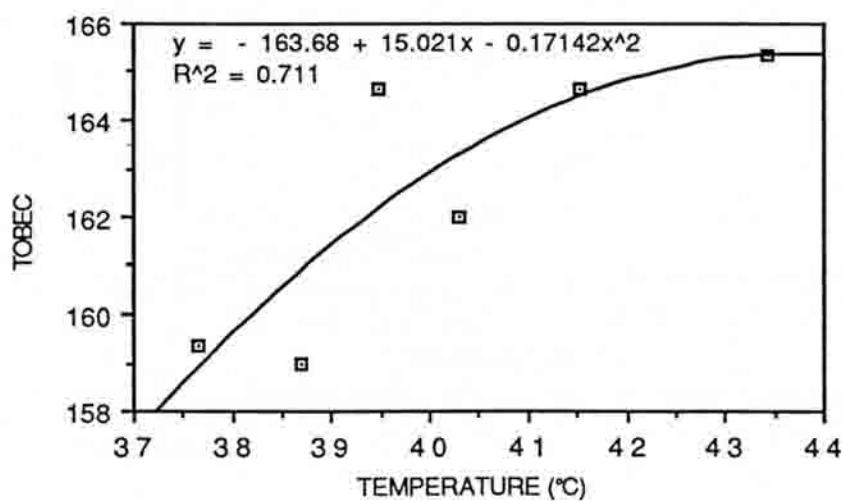


FIGURE 4. TOBEC as a function of body temperature for bird 1.

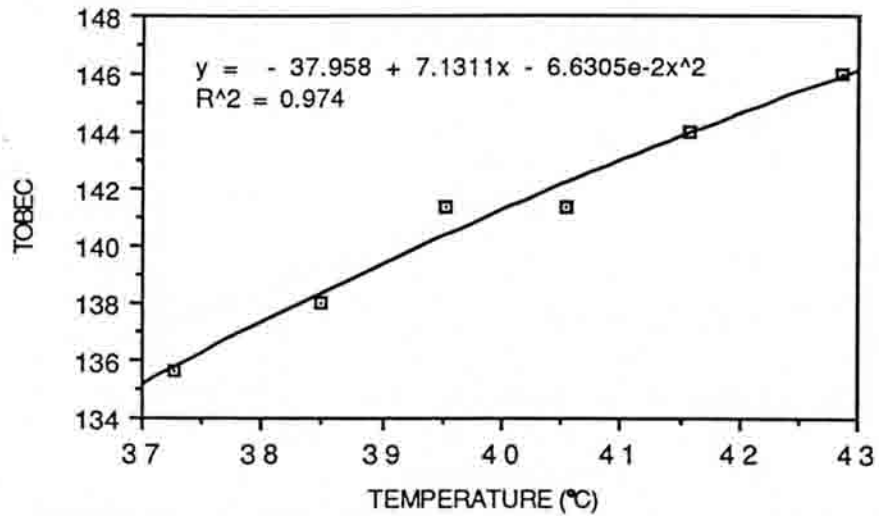


Figure 5. TOBEC as a function of body temperature for bird 2.

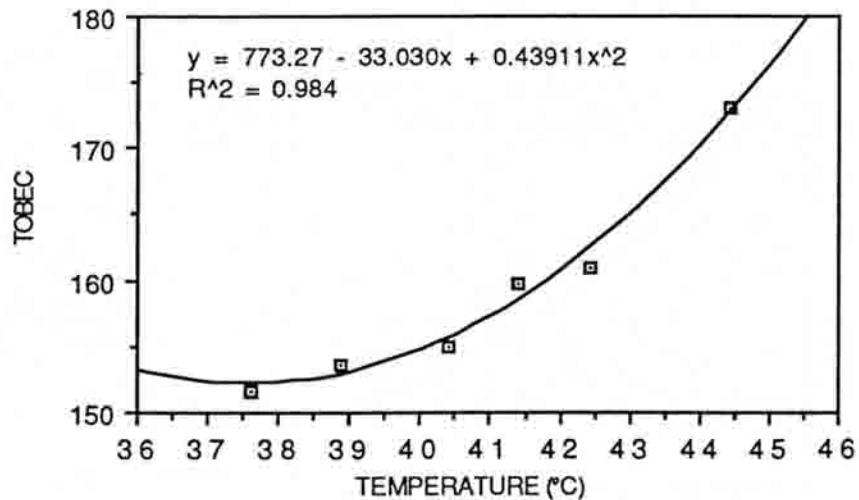


Figure 6. TOBEC as a function of body temperature for bird 3.

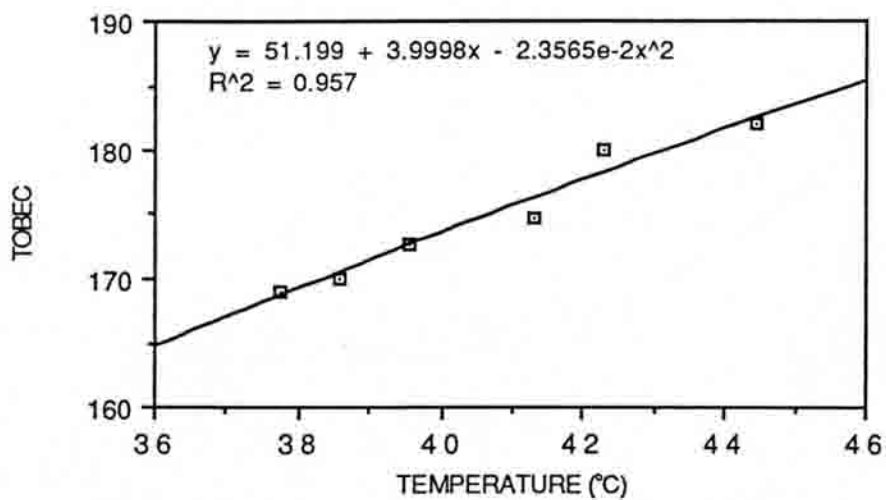


FIGURE 7. TOBEC as a function of body temperature for bird 4.

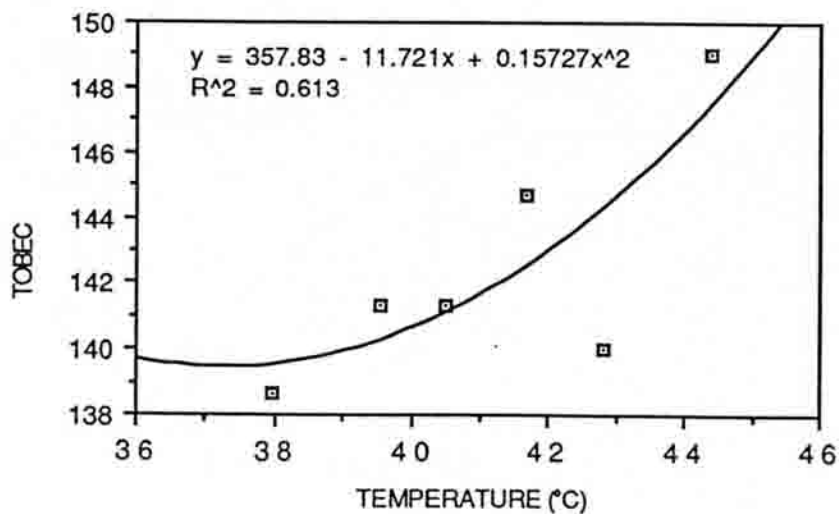


FIGURE 8. TOBEC as a function of body temperature for bird 5.

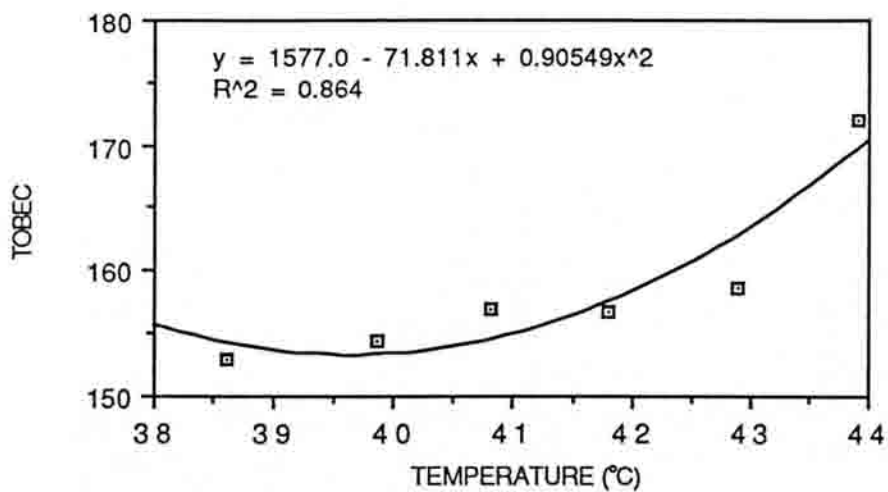


FIGURE 9. TOBEC as a function of body temperature for bird 6.

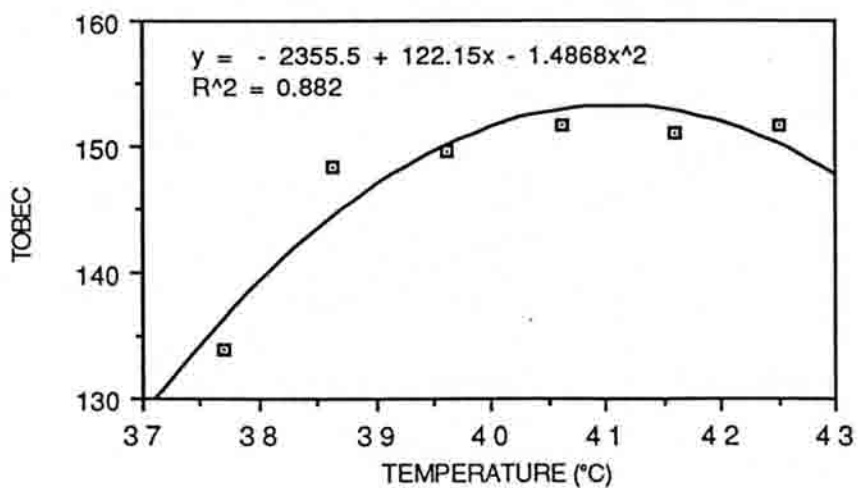


FIGURE 10. TOBEC as a function of body temperature for bird 7.

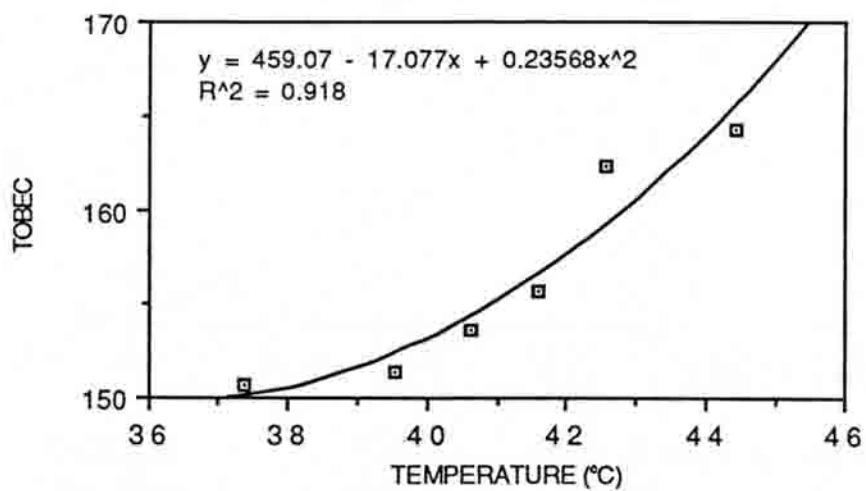


FIGURE 11. TOBEC as a function of body temperature for bird 8.

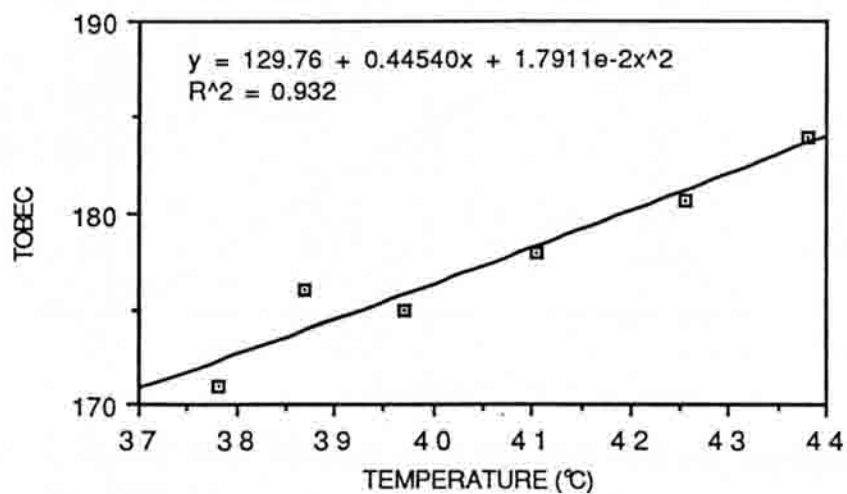


FIGURE 12. TOBEC as a function of body temperature for bird 9.

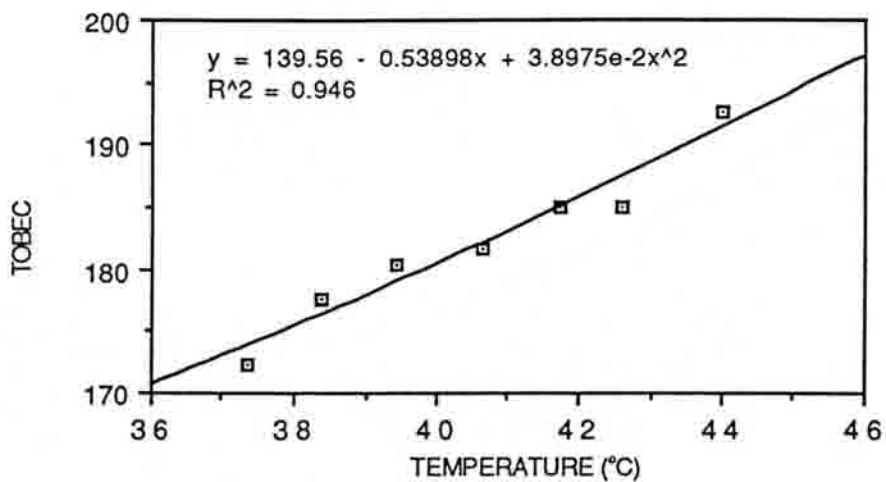


FIGURE 13. TOBEC as a function of body temperature for bird 10.

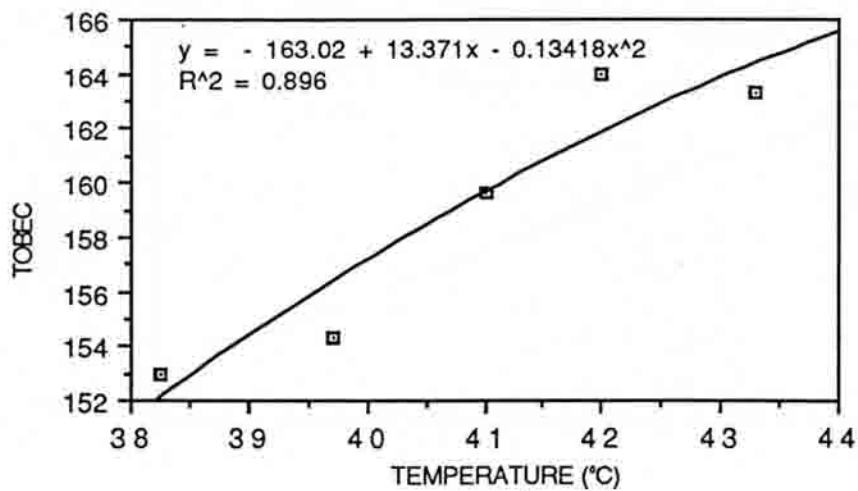


FIGURE 14. TOBEC as a function of body temperature for bird 11.

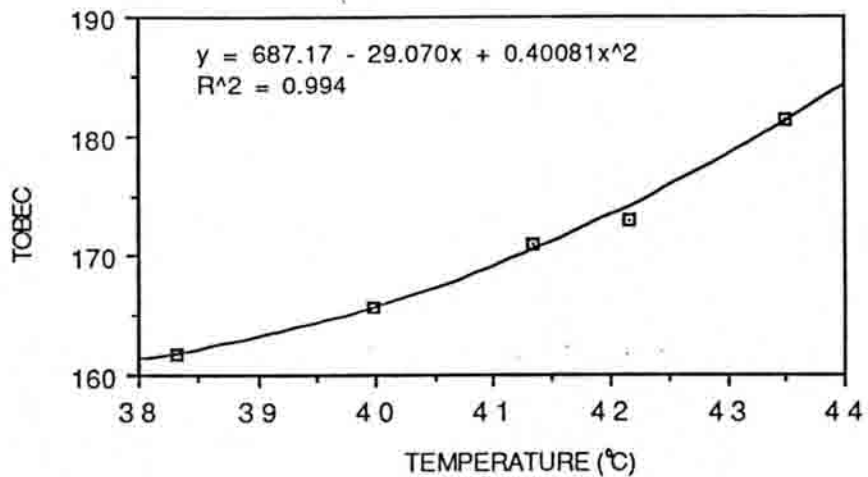


FIGURE 15. TOBEC as a function of body temperature for bird 12.

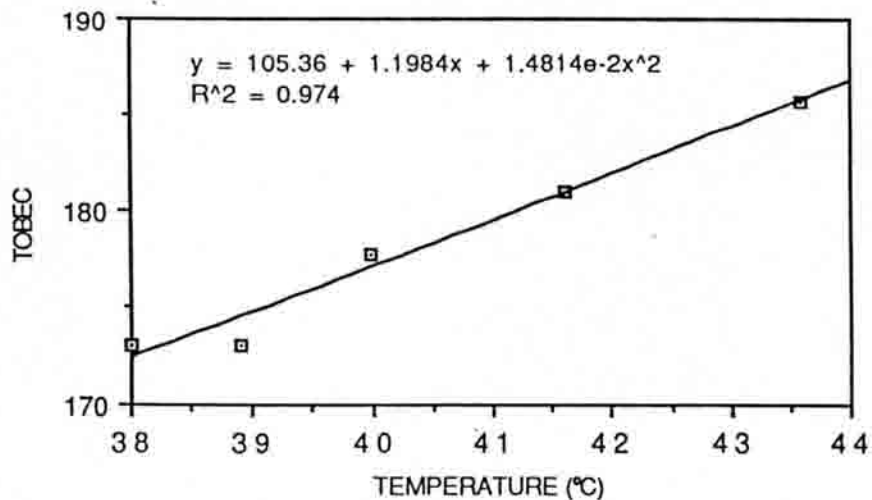


FIGURE 16. TOBEC as a function of body temperature for bird 13.